Assessing User Behaviour for Changes in the Design of Energy Using Domestic Products

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Abstract - **This paper explores the contribution that user behaviour could make to the creation of new energy efficient products. It does this by first looking at the energy demand of 6 households then discusses the identification of the products with the highest potential for improvement. This is then narrowed down to products with a high energy impact and those where a high level of human interaction and use is also evident. A model for guiding design changes based on a theoretical minimum energy level for each product is presented. The paper ends with a behaviour based design assessment procedure based on the results of the 6 household study.**

Index terms - **Eco-design, energy efficiency, user behaviour, behaviour analysis, domestic energy, theoretical minimum.**

I. INTRODUCTION

The domestic sector uses 30% of the UK's energy demand, with 25% of this from lighting and appliances. Domestic energy is the single largest sector of energy use in the UK after transport (34%) [4], and is predicted to rise with a growing trend in reliance on electronic appliances in the home and the growth in high energy using goods such as large screen LCD and Plasma televisions. It is argued that achieving improvements in energy efficiency in this area requires both research into highly efficient products and studies on consumer attitude and behaviour.

Consumer attitude and behaviour affects energy efficiency at two points in the product cycle, Point-of-Sale and Point-of-Use, [16]. Point-of-Sale energy savings are influenced predominately by consumer attitude towards energy efficiency and environmental issues in general, product marketing and product policy such as government policies on energy labels and efficiency ratings. However reference [14], found that consumers do not always purchase energy efficient products despite their stated intentions to do so, 20% of consumers stated a willingness to pay between 10% and 20% more for energy efficient products, yet actual adoption is less than 1%. The purchase of an energy efficient product is strongly influenced by government policies relating to the sale of these goods, such as the Energy Star rating in the United States, and the European Commission's Eco-Labels and Energy Labelling Schemes [6].

User behaviour during Point-of-Use is an area in which relatively little work has been done to improve efficiency, but can be the largest user of energy in the products life cycle, the European Commission's Eco-label for dishwashers focuses on 'energy and water use' during the use stage indicating that this element of its life cycle contributes the largest environmental impact [1]. A Life Cycle Assessment study into fridges by [12] showed that 90% of total energy use of a refrigerator during its lifecycle (manufacture, use and disposal) came from the use phase during its life.

Reference [16], cite studies, in 1978, 1981 and 1996, from the United States, the Netherlands and the UK which estimated that 26–36% of in-home energy use is due to resident's behaviour and found that a major untapped route for achieving energy savings in the domestic sector is to identify and implement means for influencing end users before, during and after they use appliances alongside those already applied at the points-of-sale. This is supported by studies by [3], who reports that significant energy savings can be made by providing antecedent information about methods of energy conservation and cites a 60% reduction in unnecessary lighting use simply by putting signs near light switches.

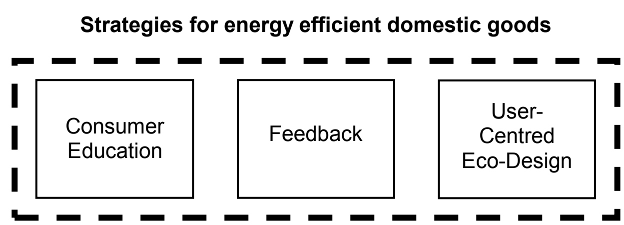

Fig. 1. The Three Strategies for More Energy Efficient Domestic Goods Usage

Figure 1 shows three effective strategies in creating energy savings from the usage of domestic products. The first relies on using existing products but with a greater consumer education, raising awareness of environmental and energy issues and improved instruction on efficient use. A study by [8] highlighted this issue with more than 80% of the households surveyed having a computer but half of the respondents did not know that it is possible to use software that sets the computer in a low power mode after a certain time of inactivity. Reference [15], reported a 10% reduction in energy-consumption after subjects had seen a 20 minute TV program about energy saving. Studies involving this antecedent information alone often saw a temporary effect of initial savings but then drop back to a much lower level. This information needs to become part of the common knowledge of users, replacing old habits with new energy reducing behaviour.

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The second strategy relies on providing feedback to the user. This could be in the form of intelligent, easy to read household electricity meters that provide instant consumption readings or feedback from the product itself that instructs the user of inefficiency, an example of this already on the market is an alarm on a refrigerator door that sounds once it has been left open beyond a predefined time. More frequent reading and paying of domestic electricity consumption has been shown to increase user awareness and reduce consumption. Approximately 85% of electricity consumers and 90% of gas consumers in the UK, 2004, pay for their energy in arrears [10]. This is not conducive to conservation, or to control of costs. Utilities in towns in Ontario Canada have experimented with 'pay as you go' systems successfully. The local utility Woodstock Hydro claims that, although consumers do not have a clear basis neither for estimating the energy costs of individual appliances nor for prioritising energy saving actions, however if feedback of total consumption is displayed centrally in the home [16], 25% of their customers will use between 15 and 20% less energy than they were doing under the traditional system of payment [2]. Reference [3], argue however that feedback in the form of frequent billing or energy audits is inefficient, because consumers do not know the relative energy costs of the various energy using systems in their households. Senders et al., 1952, showed that feedback is more effective if it relates to individual parts of a system. Hence, feedback could be given during, or immediately after, the use of an individual appliance.

The third strategy, User-Centred Eco-Design, is the focus of this paper and is a design strategy for creating new products that use highly efficient technologies but are also designed with the user's behaviour and product use or misuse in mind. Combining a design methodology that is informed and guided by studies of human behaviour, product use and ergonomics with Eco-Design, an environmentally friendly product design approach. Making the use of Eco-Design products more in keeping with the user's lifestyle but also with the possibility of creating products where the most intuitive and comfortable way of using and interacting with a product or system is also the most environmentally friendly. It is hoped that this strategy may be able to overcome many of the pitfalls of the previous two strategies whilst incorporating many of the advantages.

User-Centred Eco-Design can work with the existing user behaviour or aim to change it with a radical new product that achieves the same end function. A User-Centred design could potentially create energy efficiencies independent of technology advances and thus creates lasting savings. It is possible to illustrate this relationship between user behaviour and product design in Figure 2.

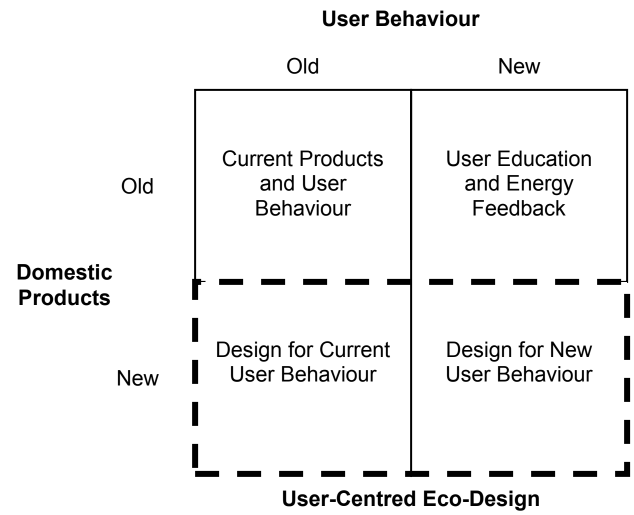

Fig. 2. The Three Strategies in Relation to Product Design and User Behaviour

A. Methodology

There are four basic questions to be asked when investigating energy use and user behaviour, these are essentially "what, when, why and how". What and when can be answered with a simple energy survey and questionnaire in which the type of appliance, its electrical power and how often it is used are recorded. The why and how are more complicated and deal with the unpredictable nature of user behaviour, looking at why appliances are being used and is there a basic function which can be achieved through a less energy intensive route? How things are used is the final question and is an important step in addressing the problem of why domestic energy use can differ by a factor of two, even when the equipment and appliances are identical [11] and [5].

The issues of why and how were investigated in an initial user behaviour study involving a two week non-intrusive video study of a sample kitchen, reported in Section V, followed by an assessment procedure for quantifying the impact of certain behaviour. In the next section some base "what" data is established.

II. Energy Study

The authors' energy study looked at domestic electrical goods, covering a wide range of products and appliances, from electric toothbrushes to dishwashers and plasma TVs. The study did not however investigate domestic space heating or lighting. Although this represents a considerable omission from domestic energy use, it was set outside of the scope of this current product / behaviour focussed work. Six domestic residences were investigated, each representing a different social demographic; a single professional living alone, a professional couple, a multiple occupancy student house with

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4 young adults living there, a family with young children, a family with teenage children and a retired couple.

A short questionnaire was prepared for each house, listing 47 typical electric goods, TV, DVD player, Hair Dryer, Washing Machine, etc… with space to add additional items if required. An interview was conducted at each house. The questionnaire was in two parts; the first asked about the type of house, how many people lived there and then took a description of their typical day and their work patterns. The second part involved being led around the house taking descriptions of electrical items and then monitoring and recording the power use in both the STANDBY and ON modes of each item. The household were then asked to say how often each item is used per day, per week or per month. From this data a total energy figure could be calculated for every item per day. Some gas-powered devices, such as water heating for showers or gas heated cooking were converted to the base unit of kWhrs of consumption for the purposes of comparison between households.

The clear leader on electricity use was the electric shower at 7 kWh per day. 12 other items also feature highly, with electricity use ranging from the washing machine at 1.46 kWh per day to 0.072 kWh per day for the toothbrush.

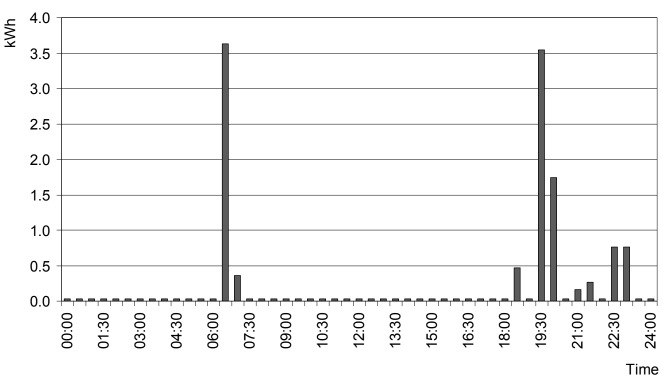

Fig. 3. Time Profile of Energy Use for the Professional Couple

Figure 3 shows the same set of data combined with a typical day time profile. The lifestyle of the professional couple shows an 11 hour gap during the day when they are both at or travelling to or from their places of work. A small amount of electricity is constantly being consumed at their home despite their absence due to the fridge / freezer and other devices always being on. This particular sample, the professional couple, interestingly and commendably did not leave many devices on standby and so this constant level of use is less than would be expected. It could be argued that this is one example of the education element of the trilogy shown in Figure 1.

Displaying the energy data in the form of figure 3, can provide useful design stimuli for system changes to energy use in the home. A long period of inactivity at the house, when the inhabitants are at work, could allow for a hotel room style 'shut-off' electricity switch, for example. Automatically turning everything off, when the owners leave, with a separate circuit for the kitchen and utility rooms, allowing refrigerated goods to remain running.

III. GREATEST POTENTIAL FOR IMPROVEMENT

The next stage of this research requires the products with the greatest potential for improvement to be identified so that a detailed user study and some new design concepts could be created and discussed. To do this it is not sufficient to only look at the highest daily energy users, table 1, since this figure does not take into account the technology efficiencies involved in performing such a function, or why the function is required. It is therefore important to consider which products could have the most potential for improvement based on the efficiency of the product, when compared to a theoretical minimum energy use, and the user behaviour. This paper begins by looking at the highest energy using products, table 1, then develops the evaluating criteria to include theoretical minimum considerations and a study of user-behaviour.

The fridge / freezer, in a number of the sample homes, was seen to be in constant use, with a high number of door openings for a variety of reasons. Each opening of the door releases the cool air into the room and the fridge must then chill room temperature air to maintain a constant internal temperature. It is easy to see how user behaviour could affect product energy use in this situation. The fridge / freezer is also a good example of a product where behaviour can affect the energy use because it does not often occur to many users that it is a high energy user. Reference [9], also found this and concluded that there are large differences between which appliances were the most energy intensive and which were *perceived to be.* In his study the fridge / freezer was the most energy intensive with energy usage ranging from 300kWh – 1700 kWh per year, with the next largest being lighting at 200 kWh – 1200 kWh. However when asking his sample which appliances they thought to be the largest users of electricity, the results put refrigeration in 7th place and lighting in 5th, highlighting the importance of education as an improvement strategy from figure 1.

The most energy demanding items in this study were the electric showers, the cookers and various computers with the accompanying screens and monitors. An anomaly of the study is caused by the small sample size that puts some items much lower in the ranking than perhaps a more extensive study would show.

IV. THEORETICAL MINIMUM

This section expands the concept of theoretical minimum energy levels for domestic goods. This can be used to identify product inefficiencies and help refine the selection criteria for the most promising targets for redesign. The heating and cooling of water is a simple case to begin with, a kettle boiling 1 litre of water, using the specific heat capacity of

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water, requires 335,200 Joules of energy, or the equivalent of 0.093 kWh. This is a simple but powerful concept, a sample kettle took 2.5 minutes to boil a litre of water and the theoretical minimum suggests that for 1 litre of water in 2.5 minutes should use at least 2.2 kW. The sample kettle performed this task and was recorded as using 2.8 kW. This is an inefficiency of 21% (the difference 0.6 / 2.8 = 21%), meaning that 21% of the energy required to boil water in this kettle is surplus to the theoretical requirements. There is clearly potential here for an improved kettle design and heating method.

Boiling water requires a certain amount of energy, a theoretical minimum energy requirement for this function, when a product's energy use *is* close to this theoretical minimum value than there is little that can be done on the product technology since it is performing the task with excellent efficiency. Perhaps a study of the user behaviour might show that water at 80^{o}C or 60^{o}C would be sufficient. This could therefore present a "New Behaviour – New Product" User-Centred Eco-Design scenario, from the matrix of figure 2. A new product concept could be developed that performed the real need of the user, rather than allowing the user to 'misuse' a product in order to achieve the desired result. If the kettle were *not* close to this theoretical minimum, it would suggest that work can be done to improve the heating effectiveness, but does not require a change in user habit to create energy savings, thus giving an "Old Behaviour – New Product" scenario.

A second worked example is of a tumble dryer that can carry a 5kg load. This load will typically contain 60% water after a 1000rpm washing cycle. To evaporate this water at a temperature of 50^{o}C, from a room temperature of 20^{o}C, using the same specific heat capacity and latent heat energy equations as before, requires a theoretical minimum of 2.09 kWh. A leading brand vented tumble dryer, for a 5 kg load, uses 3.35 kWh per drying cycle. Following the same procedure as with the kettle, the dryer has an inefficiency of 38% (1.26 / 3.35 = 38%). Work would need to be done to determine where this excess was being consumed. It maybe discovered that energy was being consumed either directly or indirectly in order to dry the clothing without putting excessive strains on the fabrics and protecting delicate items. The essential function of this product is to reduce the water content in the clothing to a level that was acceptable to the user as being dry. This could be done before the drying cycle by increasing the washing spin speed from 1000rpm to 1400rpm as this would cause a reduction in water content from 60% to 50% and although the market average is still at 1000rpm some new washing machines have speeds as high as 1600rpm.

The theoretical minimum could be used by a design team, to assess whether they should put their effort into improving the efficiency and performance of the product or introduce new behaviour changing design features, to be established by the author's research.

V. USER STUDY

The top 20 devices from table 1 have been grouped into rooms where those devices are likely to be found in a typical home. From the results, table 1, the kitchen is the single most energy intensive room with an average of 6.4 kWh per day from our six sample homes. The bathroom comes second on the table with an average reading of 5.7 kWh caused solely by the electric shower.

	Room	Total Daily Energy Use (kWh)	Average Daily Energy Use (kWh)
1	KITCHEN	38.5	6.4
2	BATHROOM	34.2	5.7
3	LOUNGE	12.9	2.1
4	UTILITY	7.0	1.2
5	BEDROOM	3.4	0.6
	Total	96.0	16.0

Table 1. Average Daily Energy Use Divided into Rooms

Based on the results of table 1 the kitchen was an obvious candidate for an initial user behaviour study. The study involved the setup and monitoring of video footage from a camera positioned in a ceiling corner of the kitchen in the multiple occupancy student house. From this viewpoint the

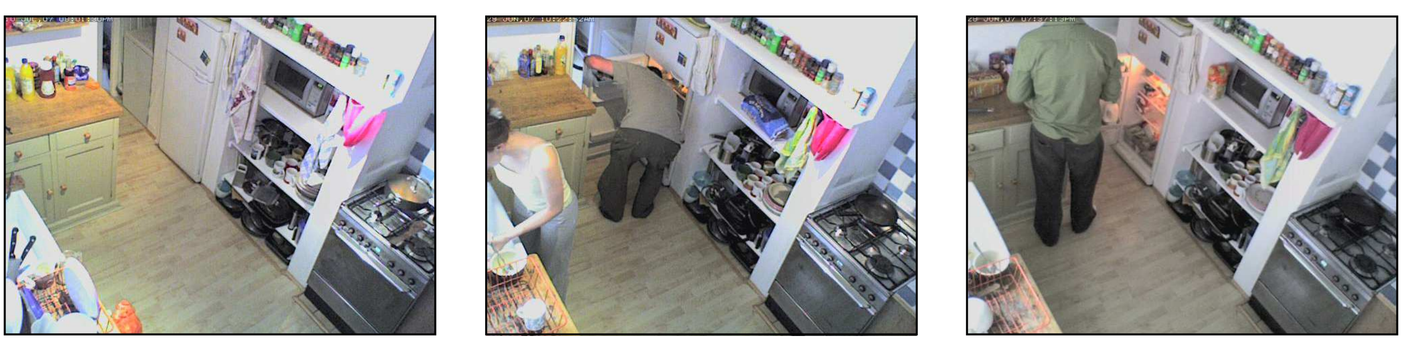

Fig. 4. Images from the Video Footage of the Kitchen

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camera could observe the actions of the inhabitants in the kitchen, with a wide view of almost all appliances. Video footage was recorded on a motion detection system so as not to record hours of inactivity, for a period of two weeks. This house was chosen for the study because of the high occupancy level of four adults it was possible to record a high variety of different behaviours all in the same environment from a single camera.

The video footage, example images of which are shown in figure 4, shows several people performing their daily activities with a high level of interaction with the refrigerator, kettle and cooker. The actions of the kitchen users were logged against a time line with a description of the activity and who was performing the action, a section of the log is shown in table 3. Table 2 shows a snap shot of activity in which two people are preparing breakfast.

Time	Action
08:21:14	Microwave finishes cooking
08:21:17	Person A opens microwave and inspects food
08:21:22	Person A removes food from microwave
08:21:24	Person B opens freezer and looks inside
08:21:26	Person B closes freezer
08:21:26	Person B opens fridge
08:21:35	Person B removes orange juice and closes fridge
08:21:37	Person B drinks orange juice
08:21:45	Person B opens fridge
08:21:46	Person A wets a cloth in the sink
08:21:47	Person B places orange juice in fridge
08:21:50	Person A begins to wipe the inside of the microwave with a cloth
08:22:06	Person B removes some food from the fridge
08:22:14	Person B closes fridge
08:22:39	Person A finishes wiping microwave and closes microwave

Table 2. Example Section of the Video Time Log

VI. BEHAVIOUR ASSESSMENT

The video time log from the user study can be organised into actions, each with a start time, person involved, product involved and the action, examples of which are shown in table 2. The data within this time log allows analysis to be made of how long particular actions took, in what order things were done and observations on how different people did the same task differently. The purpose of this analysis is to identify which are the most energy intensive behaviours, so that future product designs can address these issues as a priority. This is the guiding principle of what the author's are calling Behaviour Based Eco-Design, and is a subset of a broader User-Centred Eco-Design field.

A. Behaviour Scenarios

The first step is to create a list of all the possible ways a product could be used through a combination of brainstorming and observational studies of that product being used, these have been called the behaviour scenarios and are separated into an *action,* a simple physical task such as "open door" or "fill kettle", and a *motive,* being the why, "to look inside" or "to boil water for cooking". An example of the behaviour scenarios created for a domestic refrigerator are shown in table 3 below.

	Action		Motive	No.
1	Open Door	1	Look / Search / Sort inside	1
		2	Take out an item	2
		3	Load an item	3
		4	Load a hot item	4
		5	Load a frozen item	5
		6	Load shopping	6
		7	Play with / Boredom	7
2	Leave Open	1	Loading	8
		2	Searching / Sorting	9
		3	Cleaning	10
		4	During quick task with item	11
		5	Forgetful	12
		6	Distracted / Doing something non related	13
		7	Not closed properly	14
		8	Use as a light	15
3	Overfill			16
4	Too high a setting			17
5	Throw away unused food	1	Forgot about it / bought too much	18

Table 3. Refrigerator behaviour scenarios divided into action and motive.

Table 3 shows 18 possible scenarios for use of a domestic refrigerator, grouped under actions and then motives. These scenarios can now be matched to the video time log. For example at 8:21:24, in table 2, Person B performs scenario 1.1 for 2 seconds, the action being the first number, number 1, opening the door, with the second number being the motive, number 1 looking inside.

B. Behaviour Based Design

Once the process of matching behaviours to the log is completed the impact and thus the importance of a particular behaviour can be quantified. Table 4 shows the accumulated results from the 2 week video time log for the refrigerator and match well with other studies showing a typical range of opening times for fridge doors or between 8 and 19 seconds [17]. These results give quantifiable data to a particular

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behaviour which can now be the priority of a product's Eco-Redesign specification.

Behaviour Code	Time (seconds)	Frequency	Average Time	No.
1.1	229	16	14.3	1
1.2	464	66	7.0	2
1.3	289	65	4.4	3
1.6	20	1	20.0	6
2.1	7	1	7.0	8
2.2	72	5	14.4	9
2.4	169	7	24.1	11
2.6	81	1	81.0	13
2.7	7	1	7.0	14

Table 4. Quantifying the behaviour scenarios for a refrigerator with data from the video time log

Since the major user impact with a refrigerator is the opening of the door, allowing cold air to escape and warm air to enter, reducing this open time is a critical consideration for this product. The time taken to remove items from the refrigerator, table 4, behaviour code 1.2, is almost double the time to return that item, code 1.3. Suggesting that perhaps there is time wasted, when the door is open, for the user to search for the desired item, and choose what they wish to remove, whereas returning it requires little thinking time and a previous knowledge of where the item belongs. Coupled with this is a large amount of time associated with opening the door to look inside and sort out the contents, but not remove or add anything, code 1.1. Clearly a design priority could be a better way or presenting the contents so items can be found faster or seen without the need for opening the door. Eliminating much of the time associated with 1.1 and reducing the time needed for removing items, code 1.2.

6. CONCLUSIONS

Point-of-Use approaches to energy saving have traditionally focused on raising user awareness and providing feedback as to performance, which can have dramatic initial savings but tend not to be sustainable. This paper proposes a "what, when, why and how" methodology coupled with a behaviour assessment procedure for the study of consumer appliances in the home in order to find the behaviours that are most harmful but also to mitigate or eliminate the most damaging behaviours through product redesign.

"What" products are used "when" was established through home visits and interviews in different households. The concept of a theoretical minimum was introduced and demonstrated for two products, showing how this idea can help to identify the appropriate design strategies for different products. The "why" and "how" parts of the methodology involved studying the products in use with video. A kitchen was chosen for this initial study as it had the highest energy using appliances and was a hub of activity in the home throughout the day.

The results from the energy and user studies combine to portray a more complete image of energy use associated with appliances in the home that neither study could have performed alone. Analysing this data, using a behaviour scenario framework, allows specific behaviours to be identified as the main targets for study and products can be redesigned accordingly.

REFERENCES

[1] R. Bjerregaard, 1998, 'Establishing ecological criteria for the award of the community eco-label to dishwashers' Official Journal of the European Communities, 4 August 1998.

[2] S. Darby, 2006, The Effectiveness of Feedback on Energy Consumption, A Review for DEFRA of the Literature on Metering, Billing and Direct Displays, Environmental Change Institute, University of Oxford.

[3] M.L. Dennis, E.J. Soderstrom, W.S. Koncinski, B. Cavanaugh, Effective dissemination of energy related information, American Psychologist 45 (10) (1990) 1109–1117.

[4] DTI, 2002, Energy Consumption in the UK, Energy Publications, Department of Trade and Industry, London, UK.

[5] Gram-Hansen, K., 2003. Domestic electricity consumption—consumers and appliances. Paper, Nordic Conference on Environmental Social Sciences (NESS)

[6] International Energy Agency, IEA, 2003, Cool Appliances, Policy Strategies for Energy Efficient Homes, Head of Publications Service, Paris, France.

[7] M. Keesee, 2005, Setting a new standard – the zero energy home experience in California, Sacramento Municipal Utility District

[8] A. Lindén, A. C. Kanyama, B. Eriksson, 2005, Efficient and inefficient aspects of residential energy behaviour: What are the policy instruments for change?, Department of Sociology, Lund University, Lund, Sweden

[9] I. Mansouri, M. Newborough, D. Probert, 1996, Energy Consumption in UK Households: Impact of Domestic Electrical Appliances, Department of Applied Energy, Cranfield University, Bedford, UK.

[10] National Energy Action (NEA), 2006, Energising Fuel Direct, UK charity to promote energy efficiency, St Andrew's House, 90-92 Pilgrim Street, Newcastle Upon Tyne, UK.

[11] Palmborg, C., 1986. Social habits and energy consuming behaviour in single-family houses. Swedish Council for Building Research, Document D24:1986, Stockholm Olsson. 1995.

[12] I. Rüdenauer, C. O. Gensch, 2005, Environmental and economic evaluation of the accelerated replacement of domestic appliances, Case study refrigerators and freezers, European Committee of Manufacturers of Domestic Equipment (CECED), Institute of Applied Energy, Feiburg, Germany.

[13] R. C. Sonderegger, 1978, Movers and stayers: the resident's contribution to variation across houses in energy consumption for space heating. *Energy and Buildings* 1 (3), 313-324

[14] B. Truffer, J. Markard, R. Wustenhagen, 2001, Eco-labelling of electricity: strategies and trade-offs in the definition of environmental standards. Energy Policy 29, 885–897.

[15] R.A. Winnett, I.N. Leckliter, D.E. Chinn, B. Stahl, 1984, Reducing energy consumption: the long-term effects of a single TV program, Journal of Communication 34.

[16] G. Wood, M. Newborough, 2003, Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design, School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, Scotland, UK

[17] ELIMA European Research Project, 2005, Refrigeration product trials, Hallam University, Sheffield.

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